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OCT 26 2001
U.S. EPA REGION 10
OFFICE OF WATER

Wednesday, October 24, 2001

Jeff Kenknight
EPA Region 10
1200 6th Avenue
OW-137
Seattle, WA 98101

Dear Jeff:

At the request of Tom "Mac" Mckinsey at the Tulalip Tribes I would like to invite you to attend an open house featuring the Enviroquip Membrane Bioreactor. I have enclosed an announcement with directions to the Duvall, WA WWTP for your review.

As you may be aware, The Tulalip Tribes have selected this technology for the new plant being constructed to service the Quilceda Business Park. The plant is scheduled to be operational in 2002.

Please don't hesitate to contact me if you have any questions or require additional information prior to the open house. I hope to see you there.

Sincerely,

Jim Gleason

PHONE: 425-641-4306 · TOLL FREE: 800-454-4306 · FAX: 425-641-9270

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Kubota

Treatment Equipment
Company Presents:

OPEN HOUSE

ENVIROQUIP's MEMBRANE BIOREACTOR PILOT PLANT

Featuring **Kubota** flat plate membranes

Dates: Wednesday, Nov 7th &
Thursday, Nov 8th, 2001

Location: City of Duvall, WA WWTP
14701 Main St NE
Duvall, WA 98019

Times: Please pick the time that best fits your schedule:

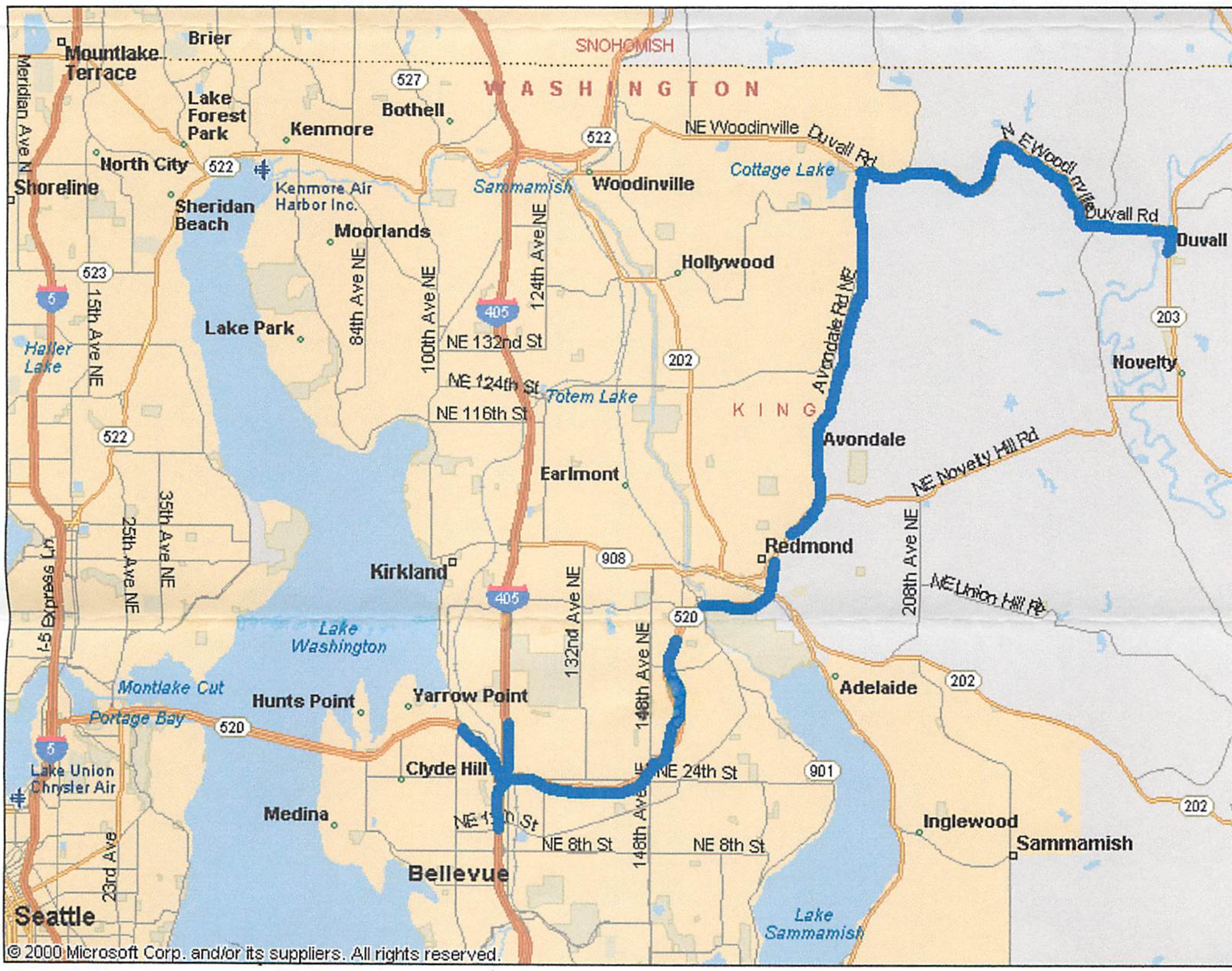
- ☐ Wednesday, Nov 7th Morning 9am – 12 pm
- ☐ Wednesday, Nov 7th Afternoon 12 pm – 3 pm
- ☐ Thursday, Nov 8th Morning 9am – 12 pm
- ☐ Thursday, Nov 8th Afternoon 12pm – 3pm

RSVP: No later than Friday, 11/02/01

Directions: Driving directions and map are attached

Driving Directions to Duvall WWTP

- From I-5 or I-405, merge onto Hwy 520 and drive East until the freeway ends at stoplight and becomes Avondale Rd
- Proceed straight through stoplight
- Go North on Avondale Rd, 5.8 miles until it ends
- Turn Right on NE Woodinville-Duvall Rd for 5.6 miles until it ends.
- Turn Right on Hwy 203 / Main St and plant entrance is 0.8 miles on right.



MBR TECHNOLOGY

Membrane Bioreactors Hit the Big Time

.......from Lab to Full Scale Application

Steve Churchouse
Duncan Wildgoose

MBR Technology
Claverton Down Road
Claverton Down
Bath BA2 7WP

MBR TECHNOLOGY

ABSTRACT

This paper reports on the recent developments in membrane bioreactor technology and the reasons behind the transformation from a high-tech laboratory system to a commercially viable process for full scale application. A review of the trends in membrane costs and performance has shown an approximate halving of the capital cost and an effective ten fold reduction in the projected operating costs since 1992.

A brief introduction of the Kubota flat sheet submerged membrane process is given together with results based upon operating experience of pilot and full scale Kubota effluent treatment plants.

A description is given of the 13,000 m^3/d Kubota sewage treatment plant currently at an advanced stage of construction at Swanage on the south Dorset coast. Additionally, the use of the process to rapidly upgrade an existing treatment plant is also illustrated with the commissioning of a large scale industrial effluent plant on Dairy waste.

1. INTRODUCTION

The last few years has seen a rapid development in the field of membrane bioreactor technology. In the space of barely 10 years, membrane bioreactors have gone from lab scale research through development to full scale application for flows in excess of 10,000 m^3/d. Indeed the development over the last over 5 years has seen a dramatic increase in both the number of operational plants and their scale. In parallel with this has been the increase in the number and diversity of applications for the technology.

For effluent treatment, submerged membrane bioreactors offer a compact system giving unrivalled effluent quality. However, 5 years ago there were virtually no operating systems and few companies had heard of let alone considered applying the technology. Then, the main disadvantages given for the technology were generally cited as:

- Untested, complex and small scale
- Unknown maintenance and labour requirement
- Concern over membrane failure rate
- No need for high effluent quality
- High cost

All of these points and have been addressed in recent years with significant progress or change in the position against each item. Commercial submerged membrane bioreactor systems have now been operational for 8 years and have proven both reliable and simple to operate. The scale of the applications has increased by more than x 100. Membrane failure rates have proven to be very low, and the increased scale and performance of submerged membrane systems has dramatically reduced costs. In addition, the introduction of higher effluent treatment charges and tighter legislation for both effluent disposal and raw water abstraction, has increasingly focussed industry on water re-use and the need to achieve higher discharge standards.

2. MEMBRANE BBIOREACTOR MARKET DEVELOPMENT

The expansion in application of membrane bioreactor technology found over the last few years can be illustrated by reference to the development of the Kubota process and is summarised in table 1.

Year	No of Plants	Largest Plant m^3/day
1993	4	125
1995	20	250
1997	70	800
1998	150	1907
1999	237	7100
2000	500	12700

Table 1: Number of installed Kubota plants and treatment capacity

The process has found application for a wide range of effluents including:

- Sewage
- Night soil and septic tank sludge
- Brewery, dairy, seafood, vegetable, bakery and canteen effluents
- Cattle and Piggery waste
- Pharmaceutical
- Photographic
- Cardboard manufacture
- Grey water recycling
- Shipboard wastewater

2.1 Trends in Process Costs

Increased application of the Kubota process has been strongly influenced by a substantial reduction in overall process costs. The main developments since 1992 allowing this cost reduction are:

- The design flux rate has been doubled with the use of gravity flow
    - Reduced plant size and power consumption
    - Reduced maintenance and labour
- Projected membrane life has increased from 3 to 8 years
    - Reduced membrane replacement/refurbishment
- Scale up of manufacture has reduced membrane fabrication costs.

- Replacement membrane panels costs have decreased by x 4 (figure 1)

In addition plant design and operation has been simplified reducing capital costs and maintenance requirements in operation.

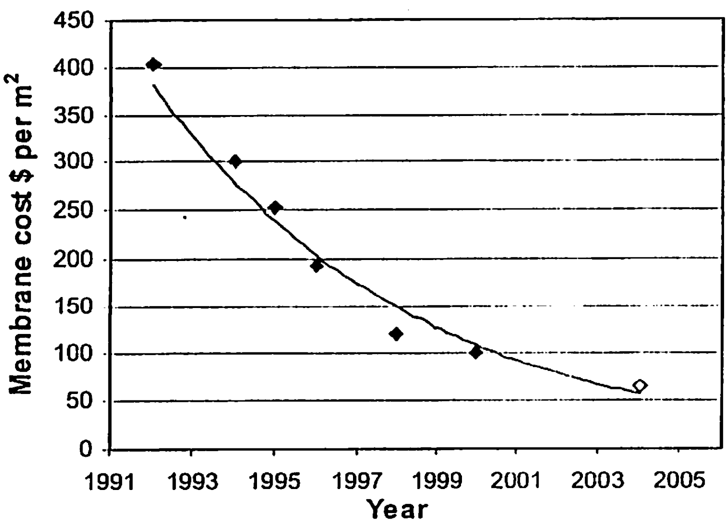


Figure 1: Reduction in actual and projected membrane replacement costs per m^2

The combined effect of these factors has enabled Membrane bioreactors to go from an expensive small scale niche application to a large scale process increasingly able to compete with conventional effluent treatment technologies. Figure 2 shows how the overall costs of submerged membrane bioreactors have decreased for an example 2000 m^3/d plant. Reference to figure 2 indicates that whilst further continued reductions in revenue costs are projected in the future, the capital cost of the plants as indicated by the amortised capital component will see marginal further reductions after the year 2000. This is as a result of the non-membrane M&E and civil items for this size of plant.

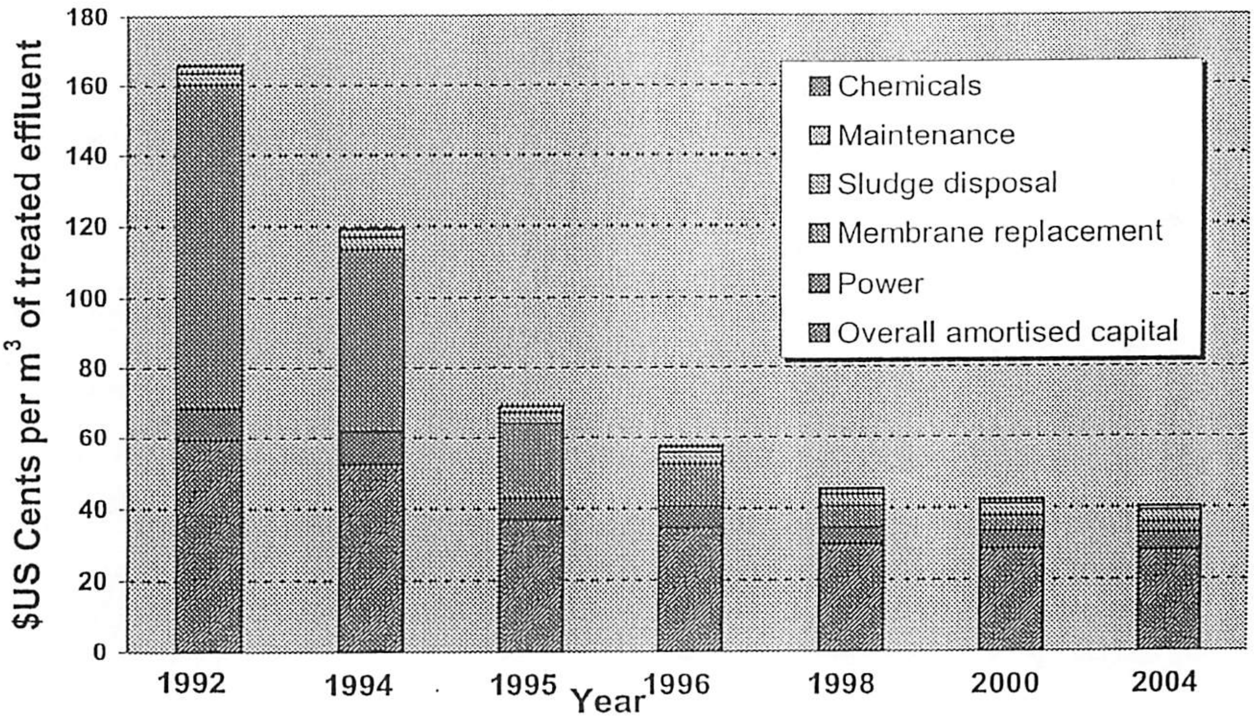


Figure 2: Comparative reduction in overall membrane bioreactor treatment cost per m^3 of effluent for a 2000 m^3/day plant at full flow. Costs per m^3 include the capital amortised at 6 % over 20 years. Capital costs include an estimate of M&E and tanks, but exclude any buildings, storm storage or sludge facilities.

As the membrane component costs are approximately linear in proportion to the volumetric capacity, the reduction in costs with increasing scale is less in proportion than for conventional technologies reliant on large civil structures. Thus for very large scale plants, conventional processes generally remain lower in cost. However, further reductions in the membrane component costs will inevitably push this economic crossover to still higher capacity. Indeed where tight effluent standards need to be met or land is restricted, membrane bioreactor systems are already being considered for treatment capacities exceeding 50,000 m^3/d.

3. THE KUBOTA PROCESS

3.1 Development

In 1989 the Japanese Government charged many of their large corporations including Kubota to invest time and money in new treatment technologies that had a low footprint and produced a high quality final effluent with re-use capabilities. Out of this initiative was developed the Kubota flat sheet submerged membrane process. This process was first utilised in a commercial treatment plant in 1990 and has now seen over 200 plants installed world-wide.

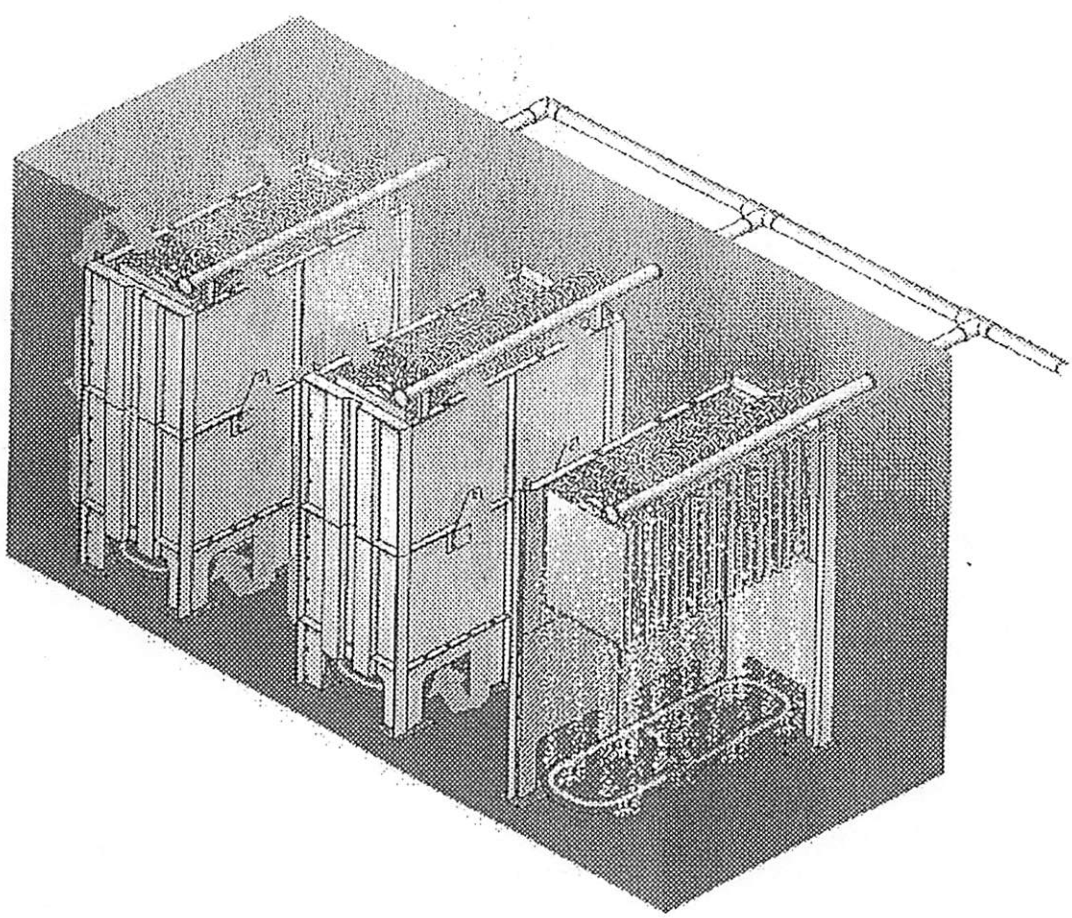


Figure 3: Schematic of the Kubota unit in operation within an activated sludge tank

3.1.1 Description

The Kubota membrane bioreactor[1,2,3] is essentially a high MLSS activated sludge process where the Kubota membrane treatment units are submerged within the activated sludge tank. Typically the activated sludge is maintained in the range 15 - 20,000 mg/l MLSS. The standard Kubota unit (figure 3) comprises two sections, the top section contains 150 flat panel membranes slotted into a GRP housing allowing a gap of approximately 7 mm between panels. The lower section of the unit contains a coarse bubble diffuser mounted within a simple matching housing. This supports the top section and channels the bubbles and activated sludge flow between the membrane plates in the upper section. The bubbles released by the lower diffuser section generate an upward sludge crossflow over the membrane surface of approximately 0.5 m/s. This crossflow minimises fouling and allows low pressure gravity filtration of the treated effluent into the membrane panel and thence to the collecting manifold. Each membrane panel comprises of a solid ABS support plate with spacer layer between it and an ultrasonic welded flat sheet membrane on both sides. Each panel has 0.8 m^2 of membrane of a nominal pore size 0.4 μm.

In operation, the treated effluent flow through the membrane units is controlled by available gravity head (typically 1-1.5 m). The number of units installed is dependent on the maximum flow rate required. A typical process flow diagram is shown in figure 4.

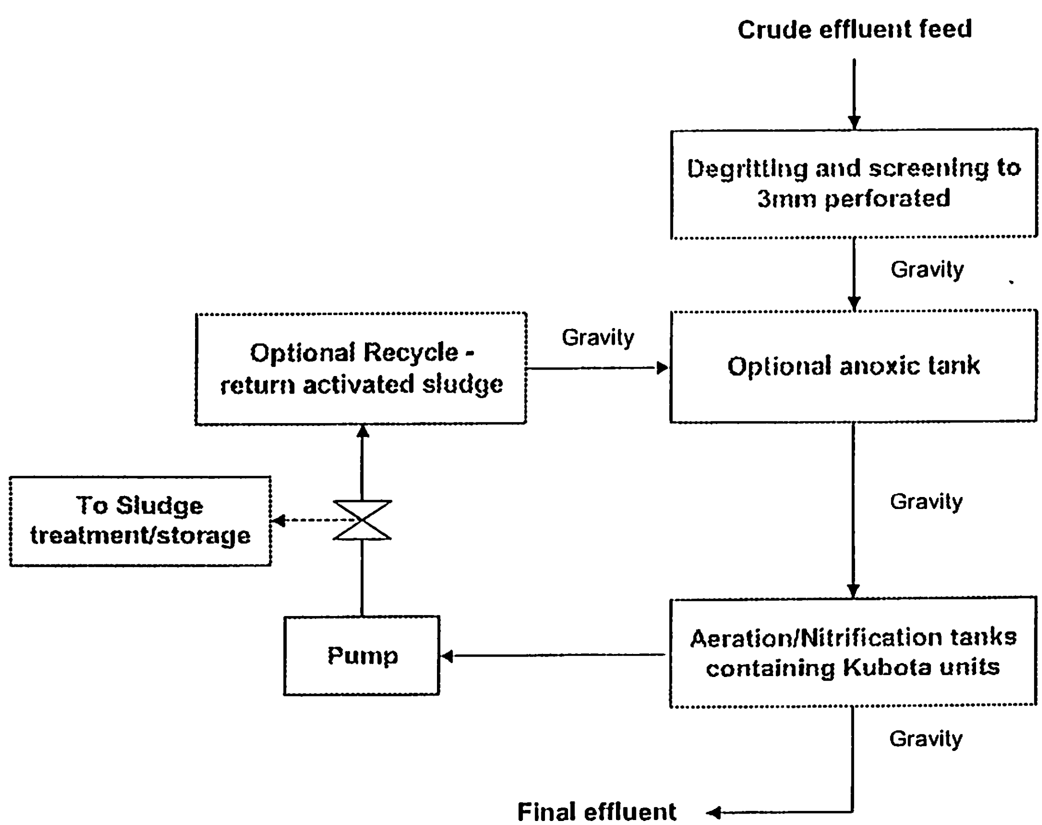


Figure 4: Typical Kubota process flow diagram

4. OPERATING EXPERIENCE

4.1 The Kingston Seymour Trial

Previous work has reported the results of a pilot plant trial of the Kubota system carried out jointly by Wessex Water, in conjunction with South West and Welsh Water[2,3]. Operation of the 100 m^3/d pilot plant was started in April 1995 and is now into its 5th year of operation. To date effluent quality has remained consistently high, with little change in permeate quality or flow rate being observed from previously reported values[2,3]. The plant has been operated without chemical cleaning for up to 18 months interval at a time, although 6 monthly cleaning is the normal recommended interval.

The plant has operated unattended with no membrane maintenance being required between the occasional in-situ chemical cleans. Approximately once per year the sludge level has been lowered to allow the membrane units to be hosed down in-situ to allow visual inspection. Chemical cleaning is carried out as an in-situ backwash with dilute sodium hypochlorite and is completed within 1 day.

4.1.1 Membrane Failure Rates

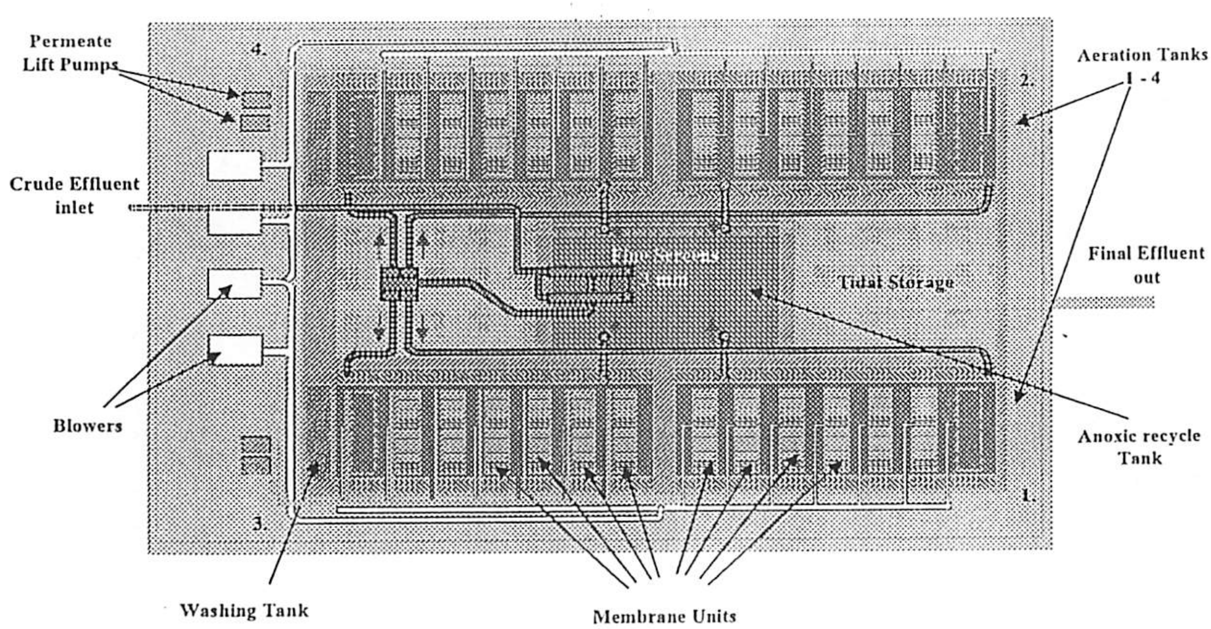
After 4 years of operation, all of the membranes were removed and individually examined for damage and signs of wear. Of the 297 original panels (3 were previously removed for destructive testing), none were detected to have failed in use. 1 panel showed gross microbial growth on the inside of the panel but no physical damage or perforation and was replaced. 2 panels showed minor wear and perforation of the membrane surface confined to an area of <4 cm^2 and 3 suffered minor damaged on the membrane surface during the removal and inspection. The damaged membranes were repaired and replaced back into the membrane units for continued evaluation. The total number of membrane panels replaced or repaired as a result of wear in use was 3 after 4 years operation of which 1 was actually replaced. The indicated failure rate of <0.25% per annum is in agreement with data from Japan indicating a failure rate of <0.3% per annum after 5 years.

4.2 The Porlock Sewage Treatment Plant

Following the successful trials at Kingston Seymour, a full scale plant has been built at Porlock on the North Somerset coast[4]. Porlock is a picturesque village location on the edge of Exmoor National Park and has approximately 4000 people within the catchment area. The site is overlooked by both the village and surrounding hills and the effluent discharges into the sea near a bathing beach. The requirement was thus for a high quality compact treatment process that could blend into the surroundings. Although the process does not need it, planning requirements dictated that the plant should be housed within a local stone faced building to fit in with the adjacent farm property.

Operation was started in February 1998 and the plant has a full flow to treatment of 1900 m^3/d. A total of 24 Kubota units are contained in four aeration compartments with the treated effluent removed under gravity through the wall of the tank (figure 5). Due to the requirement for tidal storage, pumps are used to lift the treated effluent into the tidal tank.

Figure 5: Schematic layout of the Porlock sewage treatment plant.



Effluent quality has been exceptional with performance matching that from the Kingston Seymour plant (table 2). Final effluent BOD has not exceeded 5 mg/l and has not been influenced by variations in incoming BOD (figure 6). Bacterial disinfection has averaged 6 log removal (figure 7) with virus removal averaging 4 log for both enterovirus and coliphage (figure 8). On-line turbidity has averaged 0.3 NTU.

Analyte	No of samples	Sewage Feed Average	Sewage Feed Range	Final Effluent Average	% Removal
Suspended solids / mg/l	59	230	<30-800		**>99.5**
	256			<1	
Turbidity / NTU	On-line	-	>100	<0.4	
$BOD/mgO_2/l$	61	224	<30-650		**>97.2**
	264			<0.4	
Faecal coliforms / 10^6/100 ml	55	10.1	0.9-64		**>99.9998** (>log5.7)
	252			<0.00002	
Faecal streptococcus / 10^6/100 ml	55	1.32	0.1-30		**>99.9993**
	252			<0.000011	
Coliphage virus / PFU/ml	28	811	<29-6320		**>99.98**
	125			<0.19	

Table 2: Porlock effluent quality results from February 1998 - April 1999

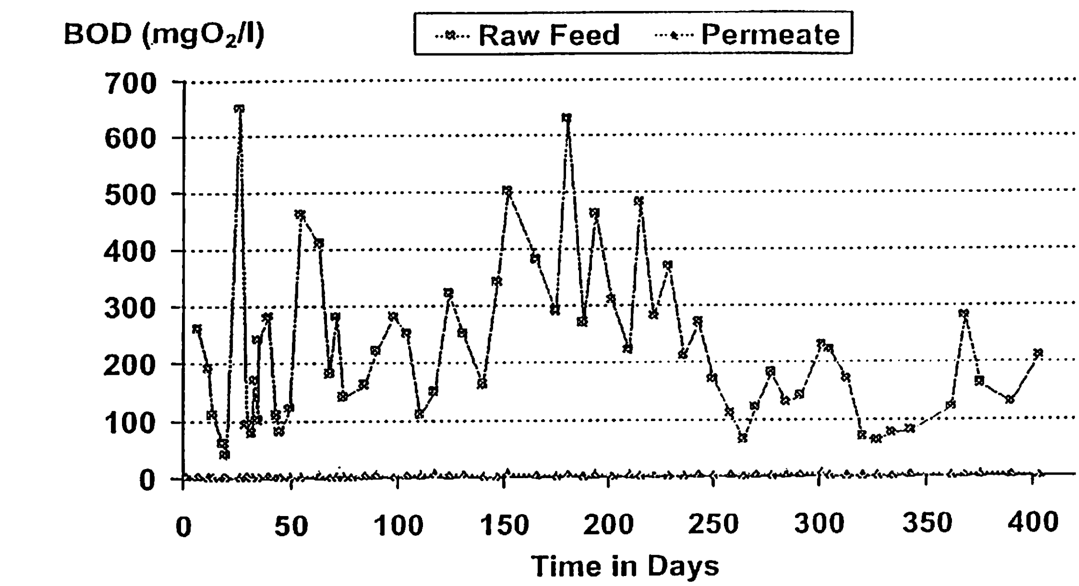


Figure 6: Porlock BOD removal for the period February 1998 to April 1999

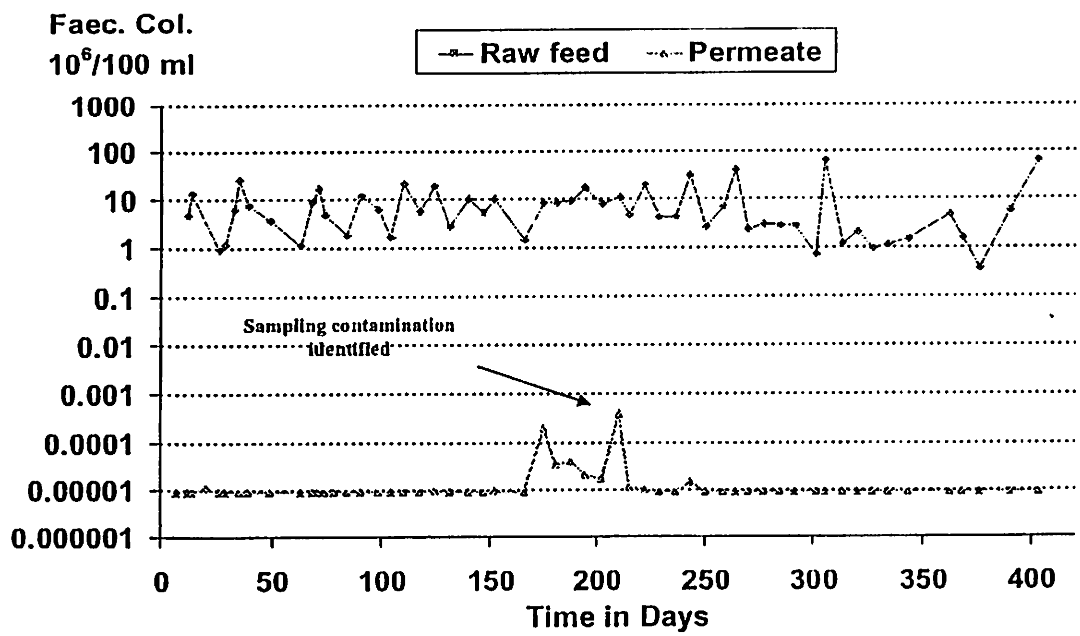


Figure 7: Porlock Faecal coliform removal for the period February 1998 to April 1999. The routine lab detection limit is 10 counts/100 ml.

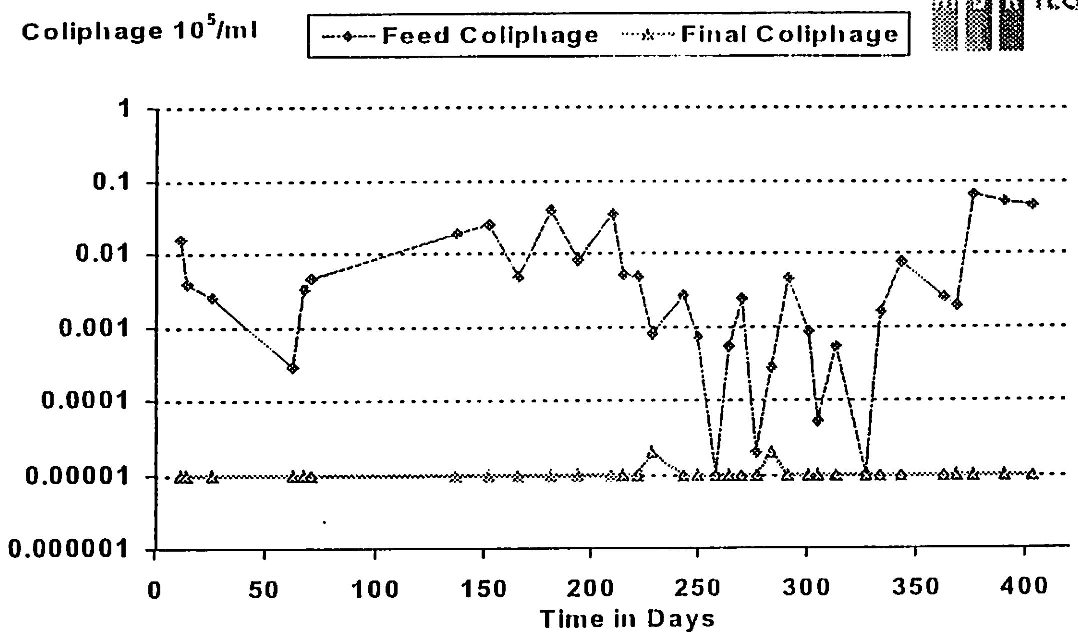


Figure 8: Porlock Faecal coliphage virus removal from February 1998 to April 1999. The routine lab detection limit is 1 PFU count/1 ml (values <1 plotted as 1 PFU/1 ml). Values from day 137 - 210 were F+coliphage from external lab data.

4.2.1 Installation and Commissioning

Installation and commissioning proved to be straightforward with membrane units tested with clean water prior to start-up with effluent. However, a few problems were identified during the commissioning of the plant and were subsequently rectified. These were principally associated with peripheral M&E equipment or the sewerage system. Those rectified included:

Substantial tidal related seawater intrusion (up to 70 % of incoming flow at times). This was due to a small section of badly damaged sewer near the beach. High and variable levels of seawater can cause biofouling due to the sudden change in the osmotic pressure on the biomass.

Poor fine screen performance (changed from 2 mm wedge wire to 3 mm perforated)

Uneven flow distribution from the flow-split chamber to the four aeration tanks

Modifications to the software control system to improve the effectiveness of a water flushing system for the aeration diffusers.

4.2.2 Maintenance and Chemical Cleaning

To date (June 1999), no membrane failures have been observed out of the 3600 panels installed. Maintenance of the membrane components has thus far been limited to the occasional water flushing through the aeration diffusers, and to cleaning of flow-meters and the turbidity flow cell.

An in-situ chemical clean with a backwash of 0.5% sodium hypochlorite was carried out after approximately 9 months operation. This required approximately 5 hours off-line for each of the four aeration tanks. Chemical costs were negligible (<£100). Used cleaning chemicals were removed by the permeate manifold and returned to the works inlet. This ensures free chlorine levels are <0.2 ppm before the tank is returned to normal operation. Measurements of THM levels indicated a maximum hourly level of 0.052 ppm chloroform in the final effluent immediately following cleaning. Chloroform levels reduced to 0.002 ppm within 24 hours. Drinking water is permitted to contain up top 0.100 ppm chloroform under current legislation in the UK.

4.2.3 Foaming

Foaming has been observed on one occasion at the plant due to an incident where a large quantity of scented surfactant appeared in the sewage feed. The foaming was rapidly controlled by allowing the foam to overflow to the central anoxic tank where a single spray could be set up. No other foaming or sludge bulking has been observed.

4.2.4 Sludge Production

Sludge ages for the plant have generally been in the range 30 - 60 days depending on season. Sludge production has been measured in the range 0.38 - 0.5 kgds/kgBOD. This equates to 3 - 6.5 m^3 per day of 2% sludge at Porlock dependent on season (Porlock has an increased summer population).

4.2.5 Odours

No significant odours are apparent in the aeration/membrane treatment building. Hydrogen sulphide levels of < 0.002 ppm have been measured within the building during operation. No odour control equipment has been installed in the treatment building.

4.3 The Swanage Sewage Treatment Plant

A Kubota sewage treatment plant is currently being installed at Swanage on the south Dorset coast. The plant is designed to treat a full flow of 13,000 m^3/d for a population of 23,000. The site is very confined being located between a marina and holiday homes with the town and bathing beaches a short walk away. The site is further constrained by being on a steep hillside. As the location is very visible, planning requirements dictated that the main building should be underground and landscaped over when completed. Little of the plant will eventually be visible from land. As of the date of this report, the civil structure has largely been completed, with M&E installation on-going. The plant is due to be operational in the year 2000.

The plant design incorporates 6 aeration tanks each containing 22 Kubota membrane units (figure 9). Incoming flow is degritted and screened to 2 mm, then passed to a central flow distribution tank. Flow then passes to the aeration tanks and treated effluent is removed by a free gravity discharge manifold and thence to the existing outfall. Flow control is achieved by allowing the head to vary in the aeration tanks in accordance with the incoming flow. As the incoming flow rises, the level in the aeration tank rises until the operating head across the membranes balances the permeate flow to incoming flow. If the flow drops the aeration tank level drops until the head reduces to again balance permeate to incoming flow rates.

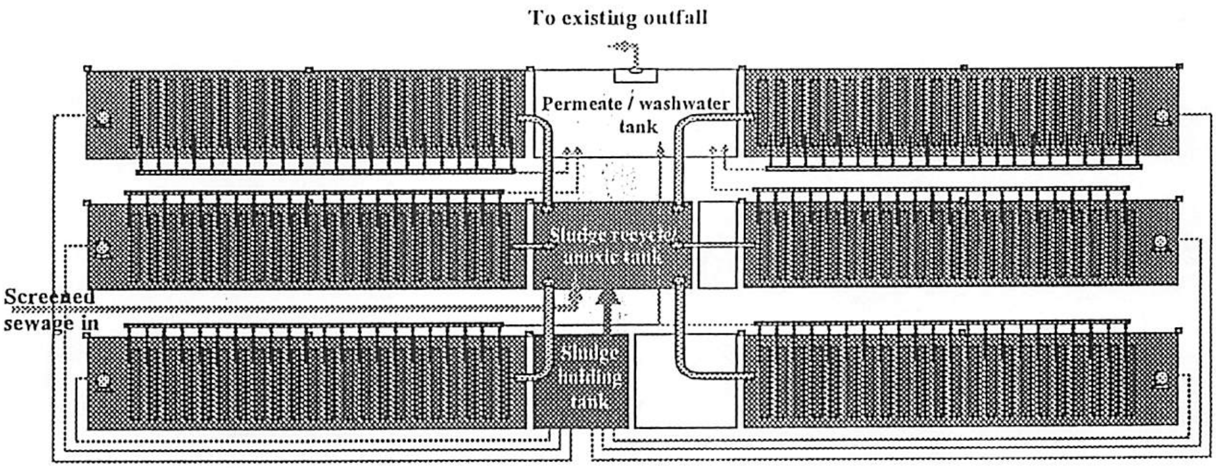


Figure 9: Schematic layout of the Swanage sewage treatment plant building

4.4 Large Scale Industrial Application

An existing dairy effluent treatment plant at Kilkenny Ireland has been upgraded by the installation of a Kubota submerged membrane plant. The overall effluent treatment plant is designed to treat approximately 20,000kg BOD per day and a maximum volume of approximately 9000 m^3/d. The Kubota membrane plant has been initially designed to treat up to 7100 m^3/d of effluent taken from the existing oxidation ditch (figure 10). This allows the MLSS and loading on the oxidation ditch to be increased whilst retaining the existing settlement tanks operating at a much reduced up-flow rate.

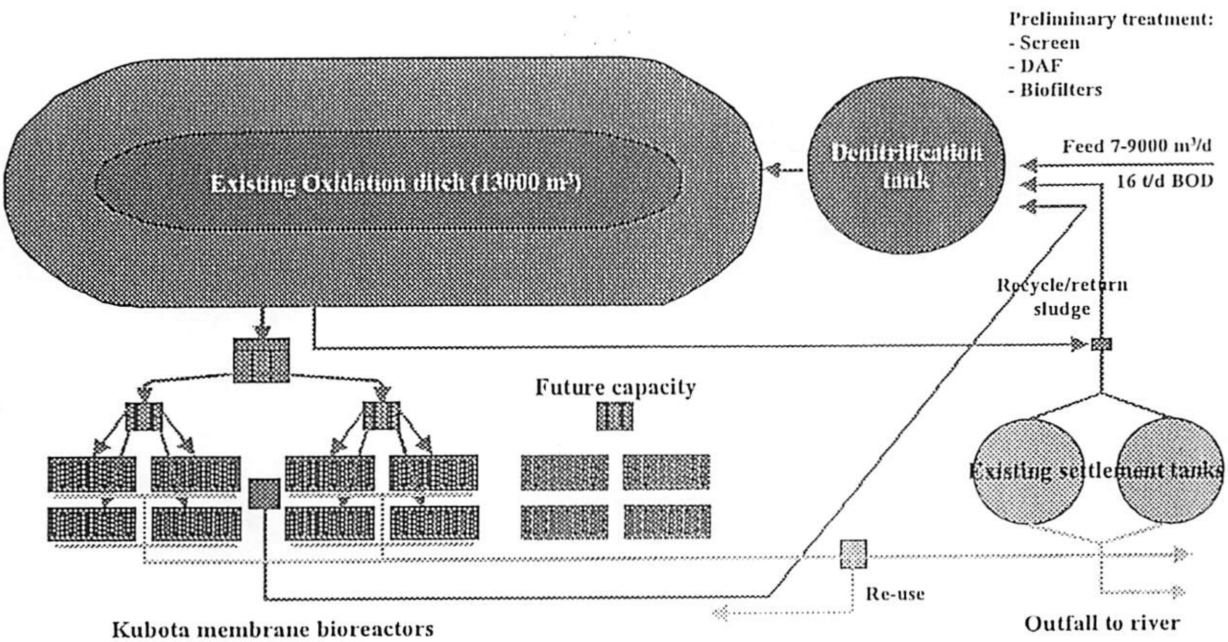


Figure 10: Schematic layout of the industrial dairy effluent treatment plant

The plant design incorporates 74 Kubota membrane treatment units within a modular arrangement of 8 steel aeration tanks operated in two groups of four tanks at a time. There are no buildings or tank covers and plant control is achieved by allowing the level to vary within the aeration tanks in proportion to the incoming flow. Each steel tank is 10 x 3 x 4 m high and the plan area of the membrane plant is approximately 50 x 10 m. Construction was started in December 1998 and plant commissioning was initiated in May 1999.

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5. CONCLUSION

- Commercial submerged membrane bioreactor systems have been operational for 8 years and have proven both reliable and simple to operate.

- Effluent quality is consistently high with full scale plants matching or exceeding pilot plant performance

- Membrane failure rates have proven to be very low, with failure rates of < 0.3% pa over 5 years

- The scale of the largest application has increased by more than x 100 since 1993.

- A review of the trends in membrane costs and performance has shown an approximate halving of the capital cost and an effective ten fold reduction in the projected operating costs since 1992 for a typical 2000 m^3/d plant.

- To date, membrane replacement costs have decreased by x 15 since 1992 (x 4 since 1995), this is as a result of:
    - Membrane manufacturing and supply price decreasing by x 4
    - Membrane design fluxes doubling
    - Projected membrane lifetime increasing to 8 years

- Reductions in the operating and capital costs for large scale plants are projected to continue present trends for the next few years, albeit at a reduced rate.

6. REFERENCES

1. H. Ishida, Y. Yamada, M. Tsuboi and S. Matsumura, (1993) 'Submerged membrane activated sludge process- its application into activated sludge process with high concentration of MLSS', Second International Conference on Advances in Water and Effluent Treatment. BHR Group series publication number 8, p321-330

2. 'Operating experiences with the Kubota submerged membrane activated sludge process', S.J. Churchouse, Proceedings of the 1st International Meeting on Membrane Bioreactors for Wastewater Treatment, 5 March 1997, School of Water Sciences/ Water Biotreatment Club, Cranfield University.

3. 'Membrane bioreactors for wastewater treatment - operating experiences with the Kubota submerged membrane activated sludge process', S.J. Churchouse, Membrane Technology, 83 (1997), p5 - 9.

4. 'Kubota Maintains Popular Trend'. S.J. Churchouse, Water and Environment International, p 26 - 27, November 1998

7. ABBREVIATIONS

ABS	Acrylonitrile butadiene styrene	
BOD	Biochemical oxygen demand	mgO_2/l
GRP	Glass fibre reinforced plastic	
M&E	Mechanical and electrical	
MLSS	Mixed liquor suspended solids	mg/l
NTU	Nephelometric turbidity units	NTU
PFU	Plaque forming units (virus)	counts/ml
THMs	Trihalomethanes	